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Fisheries Research Bulletin No. 22

The Number of Snapper, *Chrysophrys auratus* (Forster), in the Hauraki Gulf, New Zealand, Based on Egg Surveys in 1974–75 and 1975–76

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J. Crossland

Fisheries Research Division
New Zealand Ministry of Agriculture and Fisheries

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Frontispiece: One of 813 plankton samples about to come aboard.

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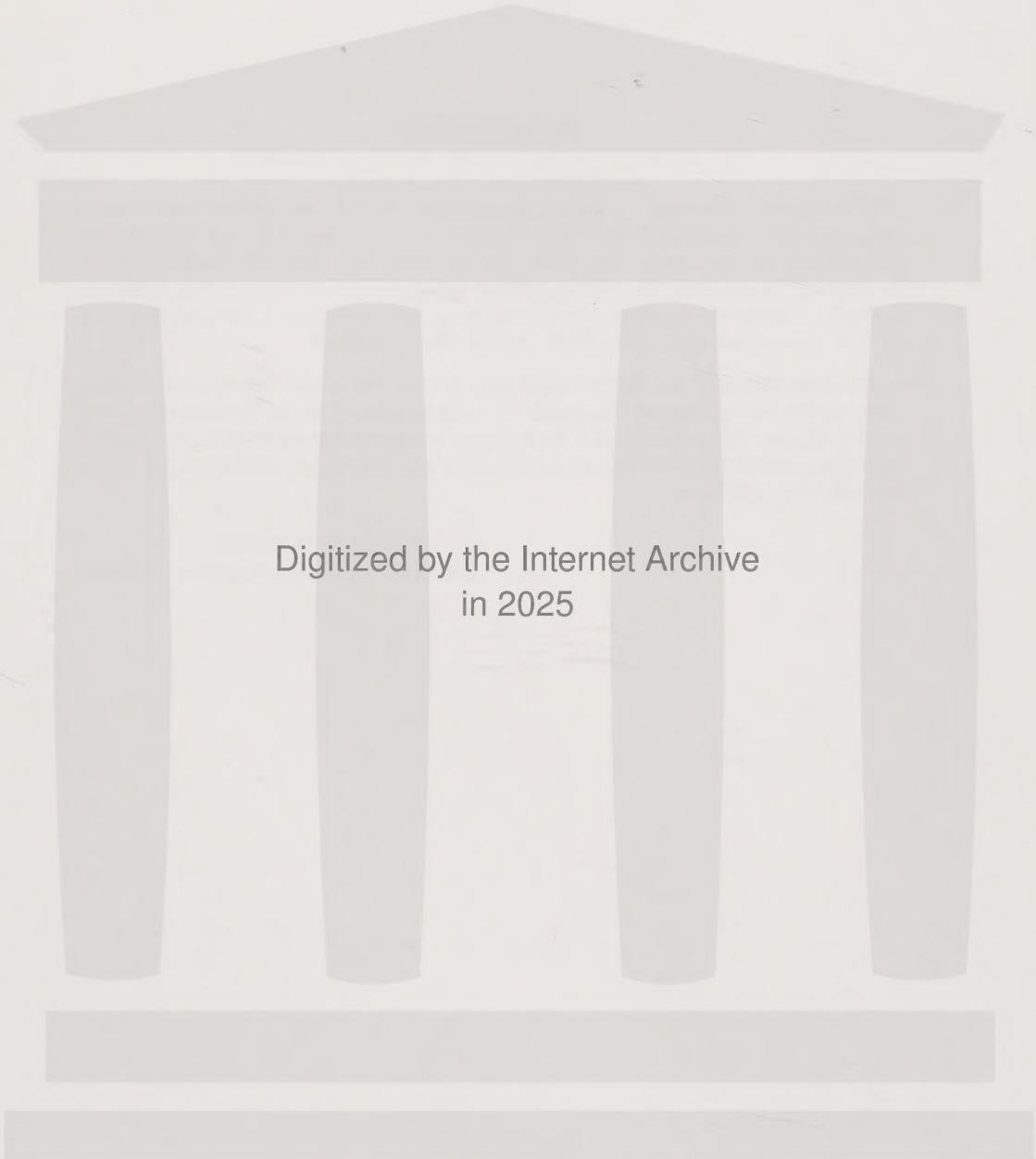
FOREWORD

THE snapper continues to be the most highly prized fish on the local market and now also commands particularly high prices overseas. By far the greatest proportion of the catch has been taken from the Hauraki Gulf, and the increasing demand for the fish has placed considerable pressure on the stock. As a result, to preserve the fish, it has been necessary to control both the quantity of fish taken and the amount of fishing effort applied.

As a background to this management it was obviously necessary to obtain data on the overall size of the resource. In this respect James Crossland's work, which is now being published, provided a useful complement to other studies aimed at estimating the size of the resource and, therefore, the degree to which it could be exploited.

G. DUNCAN WAUGH,
Director, Fisheries Research Division



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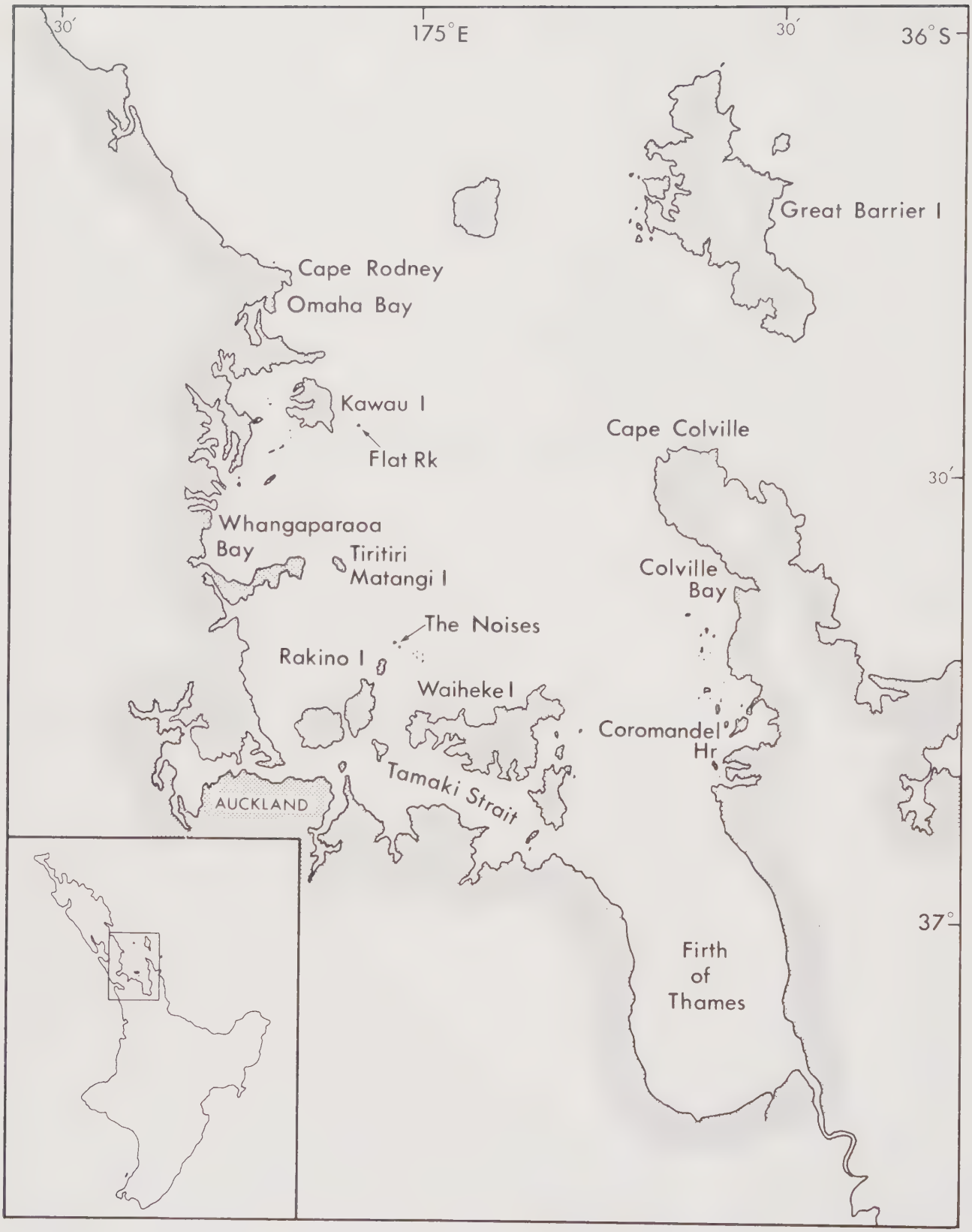


Fig. 1: The Hauraki Gulf, showing places mentioned in the text.

INTRODUCTION

In 1973 Fisheries Research Division began a detailed study on the stocks of snapper, *Chrysophrys auratus* (Forster), in the Hauraki Gulf and east Northland areas. The main objective was to obtain information to help in drawing up new regulations for the snapper fishery, particularly in the Hauraki Gulf. Several major research projects were undertaken and this bulletin presents the results of one of them, an estimate of stock size from egg surveys.

The basic theory of population estimates made from egg surveys was well stated by Saville (1964, page 164): "If one can estimate the total production of eggs or larvae of a stock, *P,* throughout a spawning season, and determine the mean fecundity, *F,* of a mature female and the proportion of females in the mature stock *K* then the total abundance of the mature stock $M = P/KF$." This principle has been used in studies which date back many years (Buchanan-Wollaston 1923) and it has been used in many parts of the world. Much work has been done in California on the Pacific sardine (pilchard), *Sardinops caerulea* (Sette and Ahlstrom 1948, Ahlstrom 1954, 1959). Recent studies include: de Ciechomski and Capezzani (1973) on the spawning stocks of the Argentinian anchovy, *Engraulis anchoita;* Macer (1974) on horse mackerel, *Trachurus trachurus,* in the English Channel and southern North Sea; and Houghton and Harding (1976) on the plaice, *Pleuronectes platessa,* in the English Channel.

Snapper has been the most studied of the marine fish species in New Zealand, and much of the biological information needed for a population estimate from egg surveys is known. Cassie (1956a) described the stages of development from fertilisation to the end of the yolk-sac larva and measured the embryonic period at different temperatures. He also delineated the snapper's principal spawning areas in the Hauraki Gulf (Cassie 1956b) and recorded the likely spawning season. Recent work (Crossland 1977a) described the reproductive cycle and established that snapper is a serial spawner. Estimates of fecundity have also been made (Crossland 1977b).

STUDY AREA

The Hauraki Gulf (Fig. 1) is a large, relatively shallow embayment with many islands and harbours. A description of its geography, climate, water temperature, currents, and tides is given in Paul (1968). The enclosed nature of the Hauraki Gulf, plus its largely resident snapper population (see Crossland 1976), make it an easily defined and suitable area for study. Previous work (Cassie 1956b) and other earlier records showed that most spawning occurred in the western half of the gulf, mainly between Tiritiri Matangi Island and Kawau Island, with a smaller concentration north of Colville Bay. A pilot survey in November 1973 confirmed this pattern and also found high egg densities in Omaha Bay and off the south-west coast of Great Barrier Island.

SAMPLING

SAMPLING PLAN

Cassie (1956b) considered a quantitative egg survey in the Hauraki Gulf was impracticable because of the highly clumped and ephemeral nature of the planktonic eggs. He apparently considered that snapper was a total spawner: "It is indeed possible that all the difference between a prolific and a meagre spawning season might be made by one very dense patch of eggs, occurring for one day only and in one small area" (Cassie 1956b, page 372). However, my studies on the reproductive cycle, fecundity, and batch size (Crossland 1977a, 1977b) showed that a mature female snapper spawns on an average only 3%–4% of its eggs at one time. I therefore decided that Cassie's appraisal was too pessimistic and that a properly planned series of stations would provide a reasonable coverage of the study area and give sound results.

The pilot survey of 1973 occupied 54 stations over 3 days (Fig. 2A). Stations at intervals of 3 nautical miles were worked along north-south and east-west transect lines. The sampling plan for the 1974–75 season (Fig. 2B) was designed after a study of the results of the pilot survey and represented the maximum number of stations which could be handled in a 5-day cruise, only daylight hours being worked. It was not possible to work around the clock with the available resources. Stations were arranged on a grid so that each was 5 nautical miles from its six nearest neighbours. This was varied slightly at some of the peripheral stations to allow for the configuration of the land.

For the 1975–76 season a slightly smaller study area was used (Fig. 2C), and stations were on a 4-mile grid. The northern limit of the study area was changed after analysis of the previous season's egg distribution, which showed that a line from Cape Rodney to Cape Colville enclosed a natural spawning area. The line also coincided with the boundary between the new fishery statistical areas 005 and 006. I considered stratifying the area for the 1975–76 season and taking samples at different distances to allow for the clumped egg distribution, but rejected this as unwise after only one full season's sampling. There were also practical difficulties caused by the shifting egg concentrations during the spawning season and the time lag between taking the samples and completion of egg counting.

Sampling was at 2-weekly intervals, except on one occasion in 1974–75, when the interval was 3 weeks. There were seven cruises in 1974–75 and nine in 1975–76. Dates and number of stations occupied are shown in Table 1. In 1974–75 the first full cruise (SE1) was too late to catch the beginning of spawning. Some data from three stations sampled during a snapper-tagging cruise 2 weeks earlier were used to provide an estimate for this period (designated cruise SE0).

SAMPLING GEAR

A cylinder-cone plankton net was used. Details of the net were: mouth area 0.25 m^2; cylinder 56 cm diameter by 150 cm long; cone slope length 185 cm; gauze 0.425-mm aperture with a porosity of 47%. The total filtering area was 2.225 m^2 and the filtering area/mouth area ratio (R) was 8.9, made up of 5.35 in the cylinder and 3.55 in the cone. The net was designed with a large R value, after the recommendation of Smith, Counts, and Clutter (1968), to give a reserve of filtering during long tows or when plankton

TABLE 1: Cruise dates and numbers of stations occupied

1974–75			1975–76		
Cruise	Date	No. of stations	Cruise	Date	No. of stations
SE0	7 Oct	3	SE1	6–10 Oct	45
SE1	21–25 Oct	50	SE2	20–24 Oct	50
SE2	4–8 Nov	46	SE3	3–7 Nov	50
SE3	18–22 Nov	49	SE4	17–21 Nov	50
SE4	2–6 Dec	49	SE5	1–5 Dec	50
SE5	16–20 Dec	43	SE6	15–19 Dec	50
SE6	6–10 Jan	47	SE7	29–31 Dec	33
SE7	20–24 Jan	47	SE8	12–16 Jan	50
			SE9	27–30 Jan	48

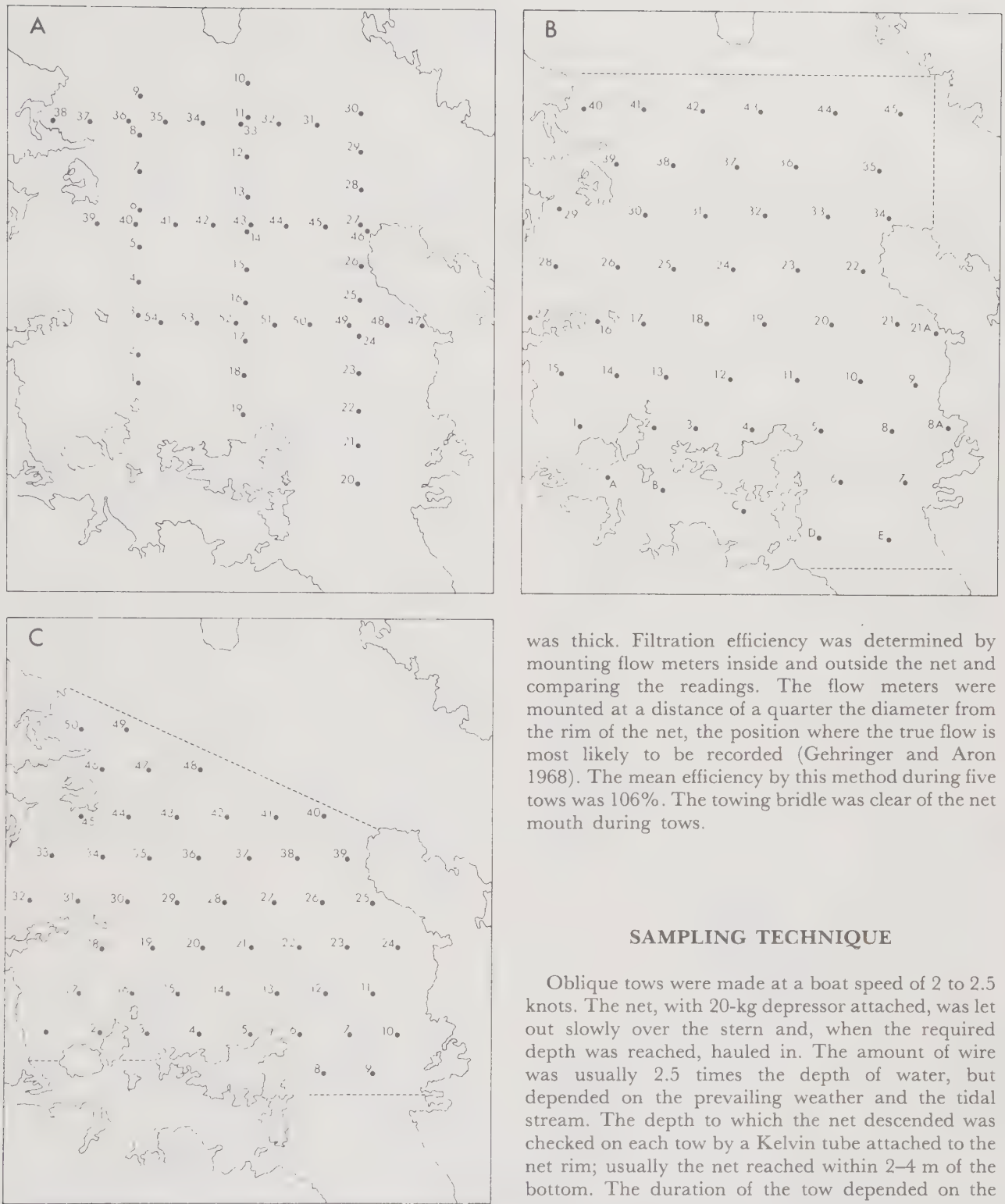


Fig. 2: A: Pilot survey stations, 1973. B: Survey stations and study area, 1974–75. C: Survey stations and study area, 1975–76.

was thick. Filtration efficiency was determined by mounting flow meters inside and outside the net and comparing the readings. The flow meters were mounted at a distance of a quarter the diameter from the rim of the net, the position where the true flow is most likely to be recorded (Gehringer and Aron 1968). The mean efficiency by this method during five tows was 106%. The towing bridle was clear of the net mouth during tows.

SAMPLING TECHNIQUE

Oblique tows were made at a boat speed of 2 to 2.5 knots. The net, with 20-kg depressor attached, was let out slowly over the stern and, when the required depth was reached, hauled in. The amount of wire was usually 2.5 times the depth of water, but depended on the prevailing weather and the tidal stream. The depth to which the net descended was checked on each tow by a Kelvin tube attached to the net rim; usually the net reached within 2–4 m of the bottom. The duration of the tow depended on the depth of the water; it was 3–4 minutes in the shallowest tows, but most were 10–17 minutes, with a towing distance of about 0.5 nautical miles. The volume of water sampled (range 50–300 m^3) was recorded with a digital flow meter, type 2030 by General Oceanics, Inc.

The sampling technique was designed to ensure that a reasonably large area was covered, which thus minimised the effect of patchiness in egg distribution (Wiebe 1971). It also ensured that all depths were sampled and so made best use of egg availability during the whole embryonic period and, to some extent, integrated over time. Cassie (1956b) took surface samples and stated that eggs were rare or absent deeper than 5 fm (9 m) below the surface. However, he also recorded that the early stages of development were seldom collected. My results from sampling at different depths off Rakino Island during the pilot survey gave the following relative densities: surface 68; 15-m depth 290; 25-m depth 78. These results were sufficient to indicate that it was necessary to sample the whole of the water column.

TREATMENT OF SAMPLES AND LABORATORY PROCEDURE

Samples were preserved in 5% neutralised formalin. The whole sample was kept, except where large medusae were present; these were removed individually.

Snapper eggs were identified from the description in Cassie (1956a) and by comparison with eggs stripped from a ripe fish and fertilised. The only eggs which could be confused with snapper, and only on a superficial basis, were those of jack mackerel *Trachurus novaezelandiae.* The diameters of the two species overlap (snapper 0.85–0.97 mm, jack mackerel 0.78–0.88 mm), but the mean size of snapper eggs is larger. The jack mackerel egg is segmented (snapper non-segmented), though this is not always apparent in preserved samples; the embryo is more pigmented than that of the snapper and has an anterior oil droplet (posterior in snapper). In some parts of the Hauraki Gulf, particularly later in the season, jack mackerel eggs occurred with snapper eggs. Plotting the frequency distribution of egg diameters of a mixed sample gave a bimodal distribution (Fig. 3). This effect was noted by Cassie (1956b), but he considered all eggs to be snapper and the apparent anomaly to have no statistical significance. However, it is more likely that eggs from both species were present in his samples.

During sorting all fish eggs and larvae were counted. Initially plankton sorters removed all eggs and larvae and sorted them according to type. Only snapper eggs are considered here. When the sorters were sufficiently experienced to identify snapper eggs accurately, these were counted *in situ* in the samples. When the size of the sample was small the whole was sorted and enumerated; when there were very large numbers of eggs, or much other material, the sample was divided with a Folsom splitter until a manageable fraction was obtained. Sorting was done under a stereo microscope with a range of magnifications of 10–40.

Cassie (1956b) considered that the shortness of the snapper's embryonic period (about 2 days) compared with other species, such as the North Atlantic cod (30+ days), decreased the chances of reliable sampling. Saville (1964, page 165), however, considered that the embryonic period should be divided into stages, that counts should be made for one stage, and that "...it [the stage] should be as short as possible to reduce to the minimum the bias in the estimate due to mortality up to the end of that stage." In this study eggs of all ages were counted and the total numbers adjusted for mortality (see section on egg mortality).

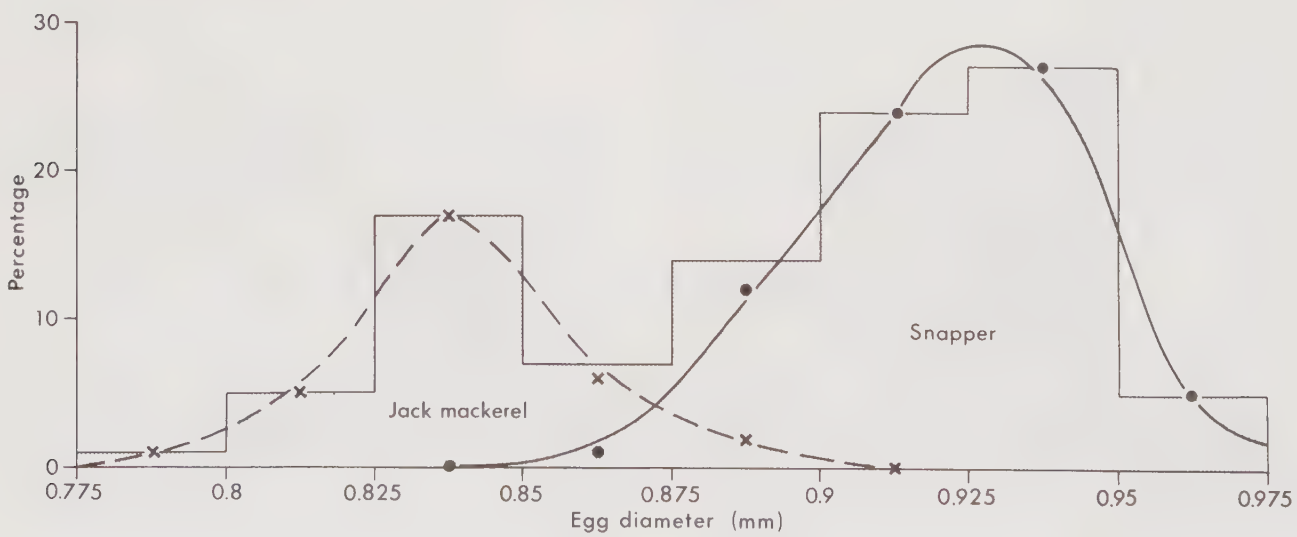


Fig. 3: Percentage-frequency distribution of egg diameters from a mixed sample of snapper and jack mackerel eggs.

EGG DENSITIES

Egg densities were calculated for each station for each cruise (Tables 2, 3, and 4). By multiplication of the egg density by the depth, the number of eggs below 1 m^2 of sea surface at each station was also calculated and this was used to depict the spatial pattern of spawning and its changes during the season (Figs. 4, 5, and 6).

SPAWNING AREAS

Spawning was concentrated along the western side of the gulf in an arc from Waiheke Island to Kawau Island and in depths of more than 20 m. The densest egg concentrations consistently occurred east of Tiritiri Matangi Island and around Flat Rock. Stations close in shore and in the Tamaki Strait contained almost no eggs. The spatial distribution was generally similar for both 1974–75 and 1975–76, except that in 1975–76 an important spawning occurred at the entrance to the Firth of Thames and around the islands north of Coromandel Harbour. Very low counts had been recorded for these areas on the 1973 survey and in 1974–75, and the number of stations had been reduced for 1975–76. A small patch of eggs occurred west of Great Barrier Island during the pilot survey and two cruises in 1974–75. This probably belonged to a spawning concentrated off the larger bays of that island; apart from this almost all the spawning occurred in the inner gulf, south of a line from Cape Rodney to Cape Colville.

TABLE 2: Egg densities (number of eggs per 50 m^3) on the pilot survey 12–16 November 1973

Station	Density	Station	Density
1	144	28	–*
2	27	29	41
3	8	30	254
4	3	31	89
5	69	32	14
6	159	33	4
7	11	34	0
8	7	35	0
9	1	36	0
10	250	37	66
11	18	38	1 477
12	4	39	134
13	98	40	11
14	71	41	7
15	138	42	4
16	655	43	64
17	1 096	44	42
18	1 001	45	8
19	653	46	3
20	6	47	240
21	39	48	364
22	64	49	196
23	124	50	410
24	93	51	163
25	28	52	1 075
26	7	53	2 225
27	6	54	281

*No sample.

SPAWNING SEASON

Previous records of spawning in the Hauraki Gulf (see Cassie 1956b) indicated that it took place from November to February. The results here showed that spawning began in October, reached a peak in late November-early December, and was almost finished by the end of January (see also Fig. 14). Egg densities indicated that spawning began about 2–3 weeks later in 1975 than 1974; otherwise the two seasons showed a similar temporal pattern. The egg concentrations

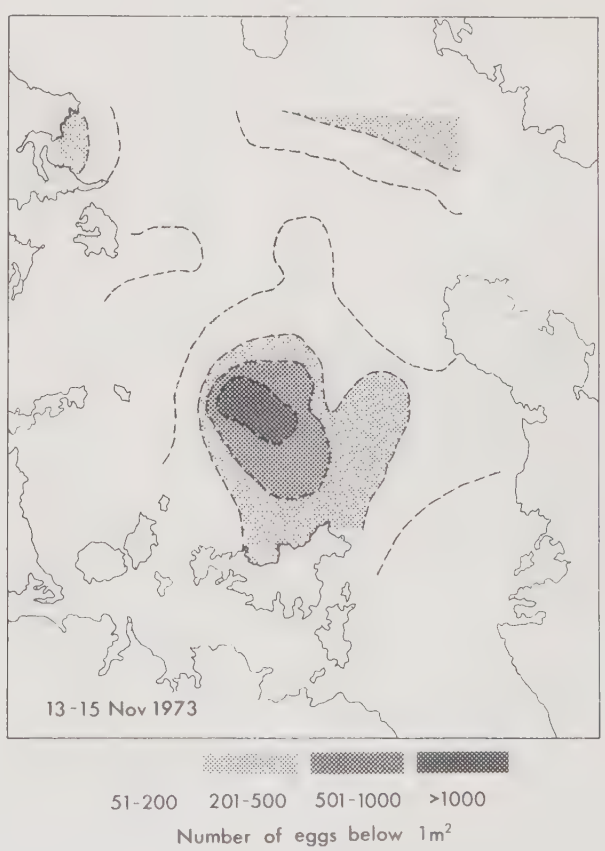


Fig. 4: Distribution of snapper eggs as numbers below 1 m^2 of sea surface, pilot survey 1973.

Inset 2*

TABLE 3: Egg densities (number of eggs per 50 m^3) by cruise and station for 1974–75

Station	Cruise							
	SE0	SE1	SE2	SE3	SE4	SE5	SE6	SE7
1	–*	144	12	249	5	53	0	0
2	–	224	382	127	4	12	0	0
3	–	1 030	1 529	626	139	68	3	0
4	–	472	92	908	34	9	1	0
5	–	103	22	129	14	8	11	0
6	–	11	3	19	1	4	1	0
7	–	32	7	66	28	15	2	0
8	–	128	37	69	12	75	14	8
8A	–	–	–	–	–	70	0	0
9	–	233	505	330	64	42	1	19
10	–	72	18	156	6	8	1	17
11	–	276	22	80	111	26	3	2
12	31	402	53	391	174	24	16	0
13	173	922	1 231	262	179	88	1	0
14	43	194	63	477	104	4	13	0
15	–	150	30	2	2	2	0	0
16	–	52	692	18	134	701	5	6
17	–	473	6 328	1 838	907	68	9	2
18	–	610	211	3 218	194	59	6	1
19	–	34	48	67	17	82	2	5
20	–	152	70	180	34	102	89	65
21	–	270	621	385	(279)†	169	147	152
21A	–	–	–	–	–	18	1	1
22	–	68	33	37	90	8	302	18
23	–	2	30	18	305	55	21	8
24	–	13	15	40	503	(304)	6	5
25	–	17	5	549	419	(265)	35	4
26	–	621	529	1 667	1 320	(798)	15	4
27	–	25	177	3	3	2	1	3
28	–	1 390	107	232	1	60	0	0
29	–	586	625	4	1	7	0	0
30	–	189	55	1 400	1 493	1 028	2 545	328
31	–	77	17	36	182	272	0	53
32	–	64	11	58	150	244	28	70
33	–	9	22	4	24	21	80	5
34	–	27	(29)	31	41	(47)	54	38
35	–	3	11	25	12	21	13	2
36	–	12	7	22	6	32	20	6
37	–	40	14	42	3	10	10	10
38	–	18	4	10	2	131	20	2
39	–	4	1 068	311	544	232	45	9
40	–	3	38	108	217	91	35	11
41	–	13	57	7	55	74	17	19
42	–	17	5	35	2	19	19	21
43	–	2	59	47	14	38	27	5
44	–	8	71	9	17	6	5	2
45	–	4	539	5	136	83	4	12
A	–	3	3	2	0	–	–	–
B	–	14	0	4	1	–	–	–
C	–	1	–	–	2	–	–	–
D	–	0	–	0	7	–	–	–
E	–	1	–	1	0	–	–	–

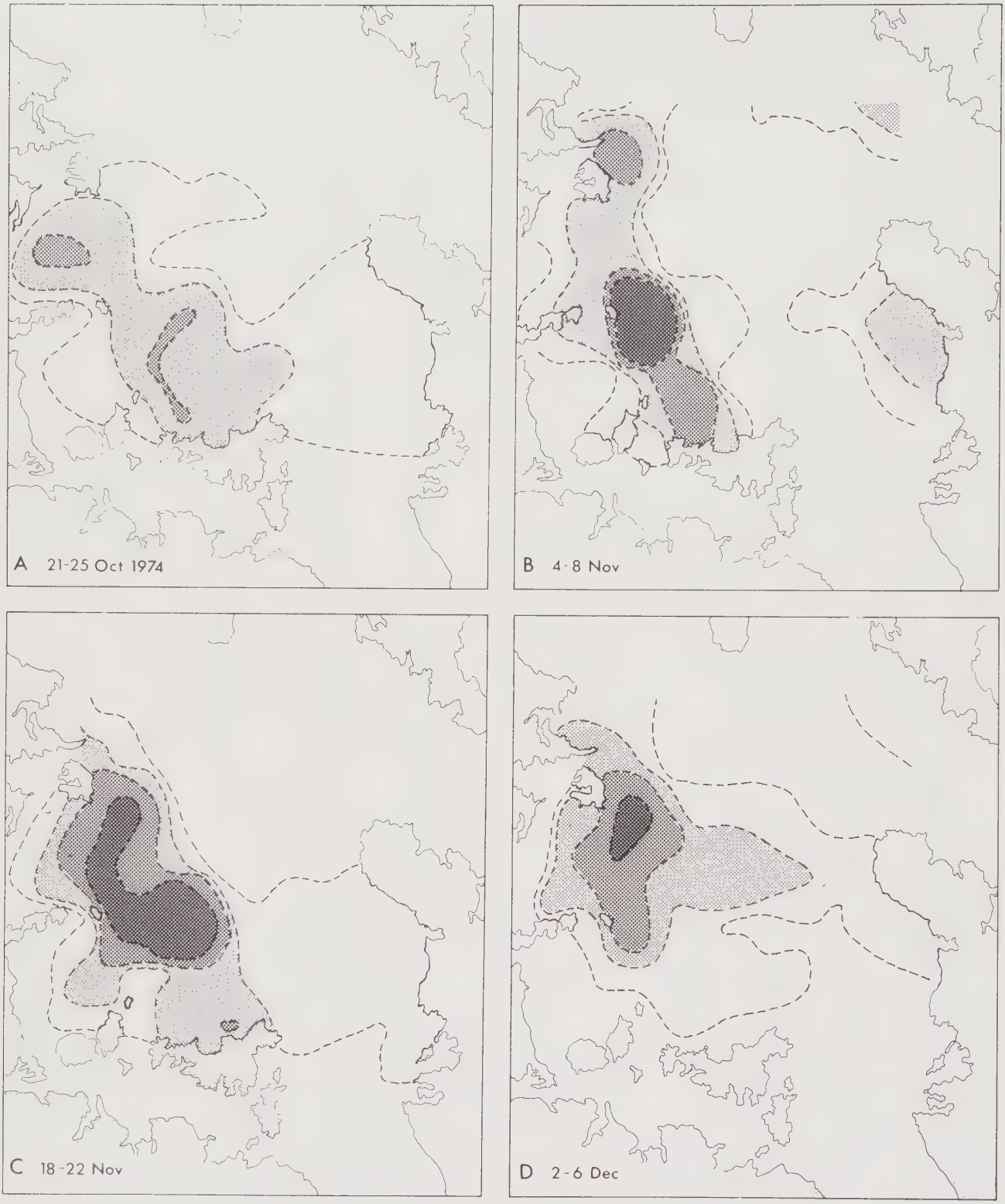
*No sample.
†Figures in parentheses are estimates.

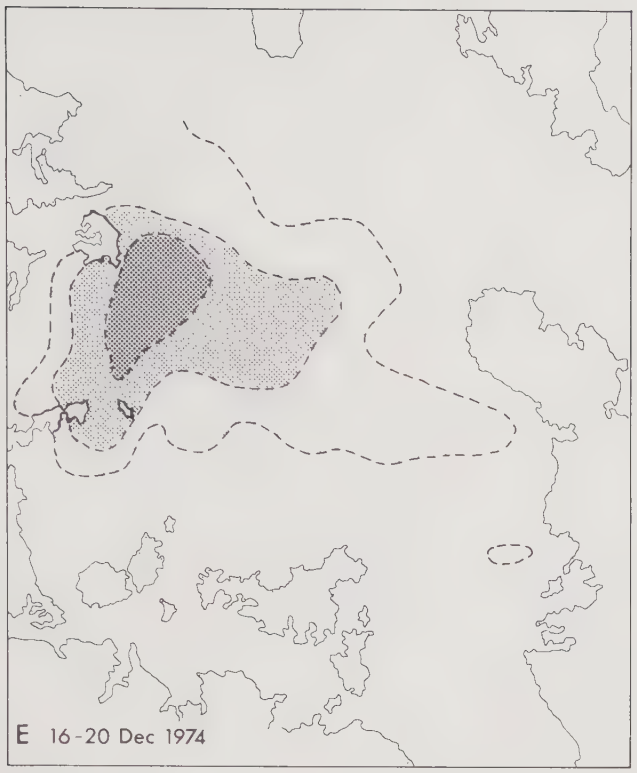
gradually moved north as the season progressed. During October spawning was centred north of Waiheke Island and in Whangaparaoa Bay; in November-early December eggs were densest from the Noises to Tiritiri Matangi Island to Kawau Island; and by January they were concentrated to the east of Kawau Island, with almost none in the southern part of the gulf.

TABLE 4: Egg densities (number of eggs per 50 m^3) by cruise and station for 1975–76

Station	Cruise								
	SE1	SE2	SE3	SE4	SE5	SE6	SE7	SE8	SE9
1	5	1	5	0	3	0	(1)*	2	1
2	16	15	85	6	15	3	(2)	1	2
3	32	56	3	1	8	3	(2)	2	4
4	129	639	2 384	13	21	66	(33)	0	28
5	55	173	1 060	67	365	257	(128)	1	15
6	14	210	135	1 109	445	286	(154)	22	23
7	1	30	15	1 021	51	164	(95)	26	3
8	3	55	100	1 258	134	11	(17)	23	1
9	1	5	60	291	51	42	(24)	7	1
10	12	41	140	370	577	383	(200)	17	27
11	2	40	20	65	35	295	(158)	21	34
12	6	107	10	250	36	144	(124)	5	8
13	11	250	130	458	103	136	(71)	5	16
14	11	7	230	147	93	150	(77)	4	0
15	121	601	40	185	105	168	(92)	17	3
16	4	56	105	743	2 034	72	(38)	6	1
17	1	78	265	111	112	267	(134)	1	4
18	14	105	1 525	845	1 614	4 036	571	42	13
19	11	90	65	1 325	214	779	916	13	3
20	13	38	945	88	3 921	615	457	60	8
21	6	15	25	9	9	81	134	24	3
22	4	109	15	45	346	100	82	40	54
23	1	27	45	217	10	134	73	35	147
24	4	44	120	94	146	443	126	55	147
25	7	13	15	381	15	63	5	39	30
26	0	2	2	3	1	8	167	4	36
27	0	36	5	2	48	427	384	43	12
28	1	5	2	25	6	162	238	9	11
29	3	47	55	17	142	17	194	95	3
30	15	64	315	98	1 115	201	81	87	10
31	2	72	625	878	179	25	105	35	1
32	255	91	735	197	20	11	1	4	5
33	149	77	565	788	287	130	66	5	3
34	73	43	55	168	523	589	1 881	16	14
35	5	32	105	14	26	299	231	829	21
36	1	1	10	7	6	3	42	64	27
37	1	8	45	5	32	21	506	18	37
38	1	12	10	2	10	15	96	10	15
39	1	3	10	17	15	48	26	12	63
40	0	1	25	1	5	7	6	1	9
41	4	2	6	6	15	89	3	16	79
42	2	11	38	24	9	13	4	16	26
43	3	13	1	15	9	19	18	12	26
44	22	64	17	54	14	48	184	63	93
45	10	16	138	475	1 031	146	44	41	59
46	(6)	11	67	140	279	43	105	86	14
47	(13)	25	45	5	43	6	28	193	9
48	(8)	16	30	108	11	116	28	7	76
49	(4)	8	17	42	5	23	10	13	(7)
50	(6)	12	45	183	56	115	174	22	(11)

*Figures in parentheses are estimates.


A 21-25 Oct 1974
B 4-8 Nov
C 18-22 Nov
D 2-6 Dec



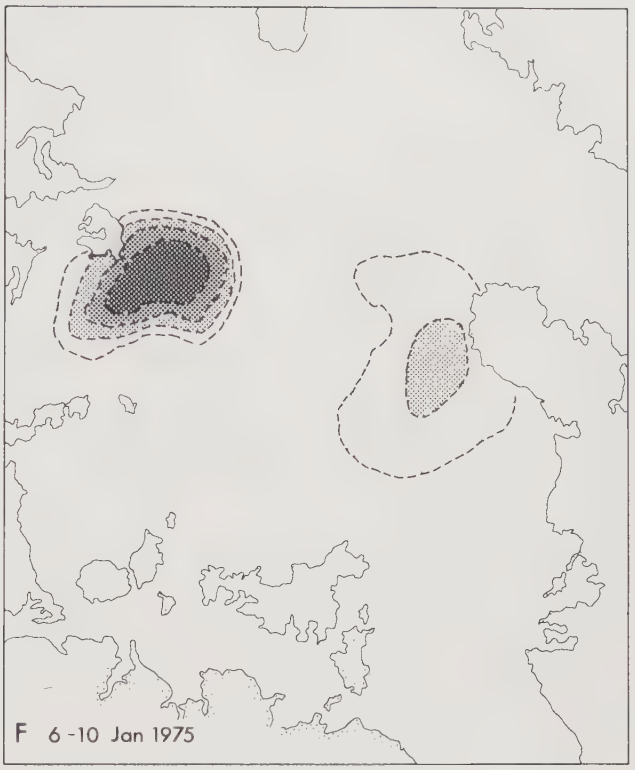


Fig. 5 (above and left): Distribution of snapper eggs as numbers below 1 m^2 of sea surface for each cruise, 1974–75.

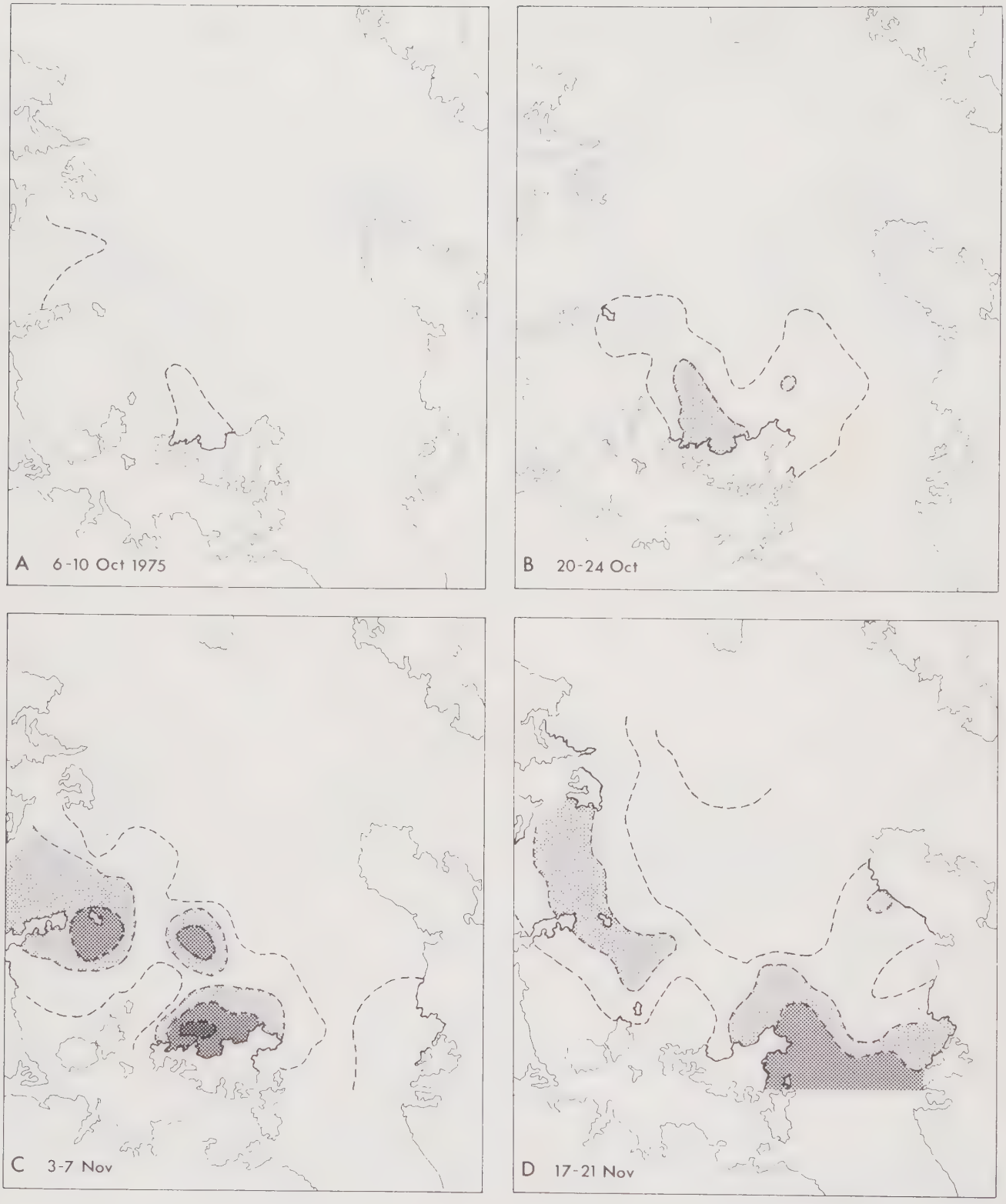


Fig. 6 (above and following pages): Distribution of snapper eggs as numbers below 1 m^2 of sea surface for each cruise, 1975–76.

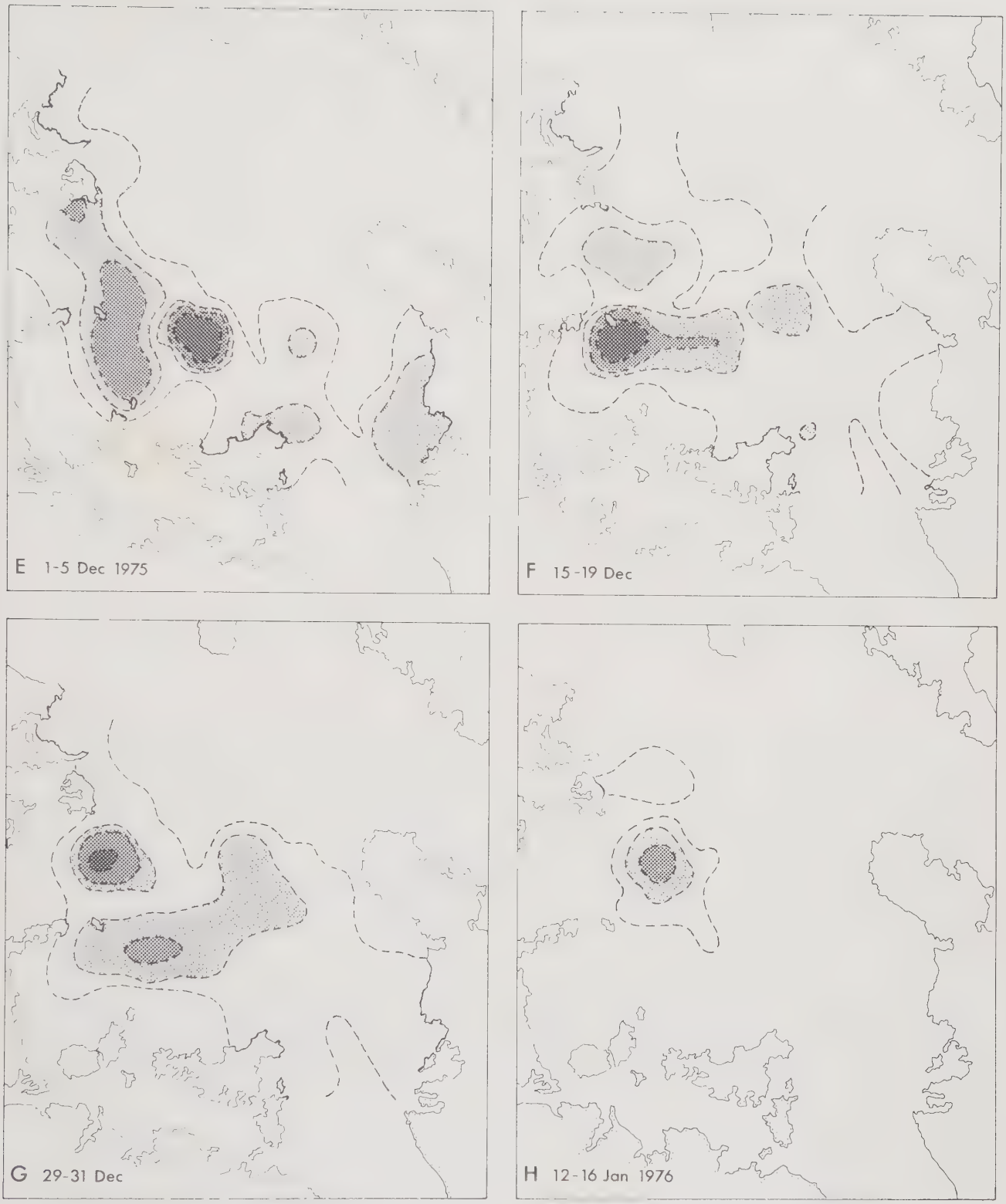


Fig. 6—*continued.*

Fig. 6—*continued.*

HYDROLOGICAL OBSERVATIONS

Information on the temperature regime experienced by the eggs is a necessary part of any egg survey. Previous results showed snapper eggs throughout the water column, so that as well as sea surface temperatures, data on the bottom to surface profiles were needed. Surface temperatures (±0.1°C) were taken by bucket and mercury thermometer at every station, but there was insufficient time for a bathythermograph cast (BT) at each. Instead, the study area was divided into subareas (six in 1974–75 and five in 1975–76) and a recording taken at one station in each (Fig. 7). The difference between surface and bottom temperatures at the BT station was considered representative of all the stations in the subarea. Half this difference was subtracted from the sea surface temperature at each station in the subarea to give the mean sea temperature experienced by the developing eggs at each station on each cruise. Because all recordings were taken during the day, there will be an upward bias in the mean sea temperature. The result of this on later calculations of the embryonic period is offset by the fact that snapper eggs are positively buoyant and float upwards to the surface layers; so they may well spend more of their time in these warmer waters.

The main features of the sea surface temperature data were the increase of temperature in the

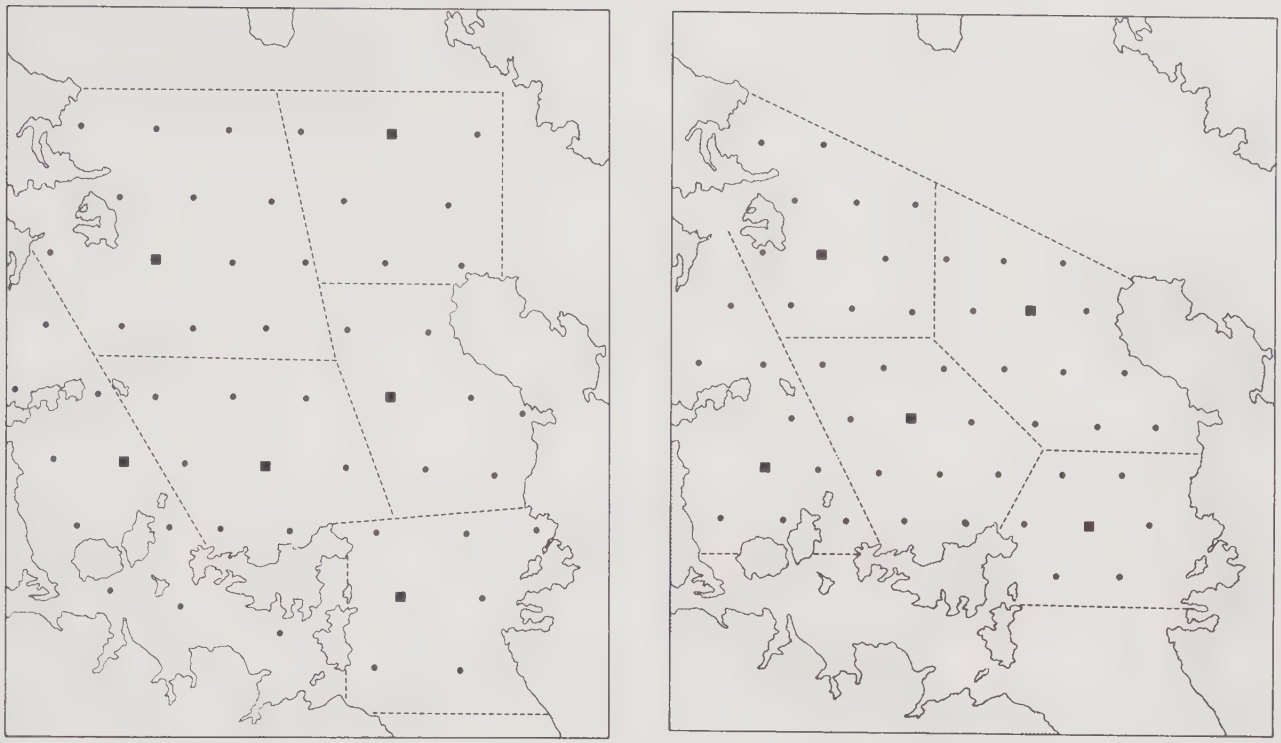


Fig. 7: Bathythermograph stations (solid squares) and subareas, 1974–75 (left) and 1975–76 (right).

shallower, in-shore parts of the gulf and the tongue of cool water projecting southwards along the eastern side (Figs. 8 and 9). Comparison of these figures shows that the sea surface temperatures in the 1975–76 spawning season were distinctly cooler than those of the previous season (see also Fig. 14). This was also true of the sea bottom temperatures, which were in the range 15.0°–20.3°C in 1974–75 and 14.4°–19.4°C in 1975–76. Surface temperatures observed were generally higher than those found by Cassie (1956b) and Paul (1968), probably because of differences in the sampling methods. Water samples for this study were taken from undisturbed water (that is, outside the boat's wake) in the top 30 cm.

TEMPERATURE AND SPAWNING

The parts of the Hauraki Gulf in which snapper spawning first began were those in which the sea temperatures were highest. Cassie (1956b) considered it likely that 18°C was a critical sea surface temperature, at which the main burst of spawning occurred. Results here have shown that appreciable spawning began at lower temperatures than this and that there was a gradual increase of spawning as the sea temperature rose (see Fig. 14). The peak of spawning in both years occurred when the overall mean sea temperature was 17.3°C. Thereafter the temperature continued to rise (with minor fluctuations) and spawning intensity decreased.

Fig. 8: Sea surface temperatures (°C) for each cruise, 1974–75.

Fig. 9: Sea surface temperatures (°C) for each cruise, 1975–76.

EGG MORTALITY

EGG STAGING

To estimate egg mortality it was necessary to age eggs found in the plankton. Cassie's (1956a) study on the development of the snapper egg was used as an initial guide to aging, but to obtain more precise data a series of aged eggs at frequent, regular intervals was necessary. For this a sample of fertilised eggs was incubated at a mean temperature of 20.9°C (range 20.5°–21.2°). Samples of eggs were taken at 1-hour intervals up to 10 hours, then 2-hourly up to 30 hours, with a final sample at 35 hours. Eggs hatched at 36 hours. The embryonic period was divided into six 6-hour stages, and drawings of these are shown in Fig. 10. The appearance of the egg at the end of each stage was as follows:

Stage 1, 6 hours: The blastoderm, now a multilayered, undifferentiated cap with individual cells visible, is still about the same size as the original germinal disc found 1 hour after fertilisation.

Stage 2, 12 hours: The blastoderm now extends slightly past the equator and its peripheral cells form the thickening precursor of the germ ring.

Stage 3, 18 hours: The embryo is now distinct. The optic lobes are visible and the caudal region has thickened. A clearly defined keel indents the yolk on the ventral surface of the embryo (at about 17 hours the blastopore closed).

Stage 4, 24 hours: Myotomes are beginning to form, and they appear as concentrations of dark lines. The tail has begun to extend beyond the edge of the blastoderm, with the oil droplet placed midway between it and the head region.

Stage 5, 30 hours: Head parts and visceral arches are now more distinct. The tail has lifted off the yolk sac at its root and extends almost to the oil droplet.

Stage 6, 36 hours: Hatching. At 35 hours the embryo is virtually ready to hatch, with the pointed tail lifted clear of the yolk. The myotomes are pronounced along the length of the embryo. The oil droplet is now located at the posterior end of the yolk sac.

By use of these egg stages a series of samples was staged. Staging was done for cruises SE1 to SE6 in 1974–75 and SE3 to SE8 in 1975–76. One hundred eggs were staged from each station in which the number of eggs was 100 or more. The percentage distribution of stages in each sample was then weighted by the number of eggs in the sample area, and the overall totals were calculated (Table 5).

DAILY SPAWNING RHYTHMS

A preliminary look at the data showed some egg stages to be under-represented in the samples and so I decided to investigate whether spawning occurred with a diel periodicity. Because sampling took place for only 12 hours (0600–1800) out of 24, a discontinuous spawning pattern would give different egg stages unequal chances of being sampled.

According to Blaxter (1969), the relationship between egg development time and temperature is curvilinear over a wide temperature range, but a linear function can be used to describe it over a narrow range. Nearly all spawning of snapper in the Hauraki Gulf occurred over a temperature range of 5°C; in 1974–75 98% of eggs were spawned within the range 16°–21°, and 95% in 1975–76. Thus, for this study a linear relationship was derived from the data of Cassie (1956a), who gave the development period at three different temperatures, and from two new observations (Fig. 11). The regression equation, calculated by least squares, was: $H = 100 - 3.06T$, where H is the development period in hours, and T is the ambient temperature in °C.

By use of this relationship the times of spawning were calculated for each staged sample. It was necessary to extrapolate for samples in which the mean sea temperature was outside the range 18°–21°C. Only eggs of stages 1–3 were used, and each of these stages was subdivided into "early", "mid", and "late" to give more precision. The results, which were combined for all cruises for each season (Fig. 12), show that snapper spawning has a distinct periodicity: it begins some 3–4 hours after dawn, peaks in the early afternoon, and continues until dusk. Thus, 92% of all eggs in the 1974–75 samples and 84% in the 1975–76 samples were spawned during the 12-hour period 0800–2000. There was some tendency for spawning to occur earlier in the day as the season progressed, perhaps because dawn was earlier.

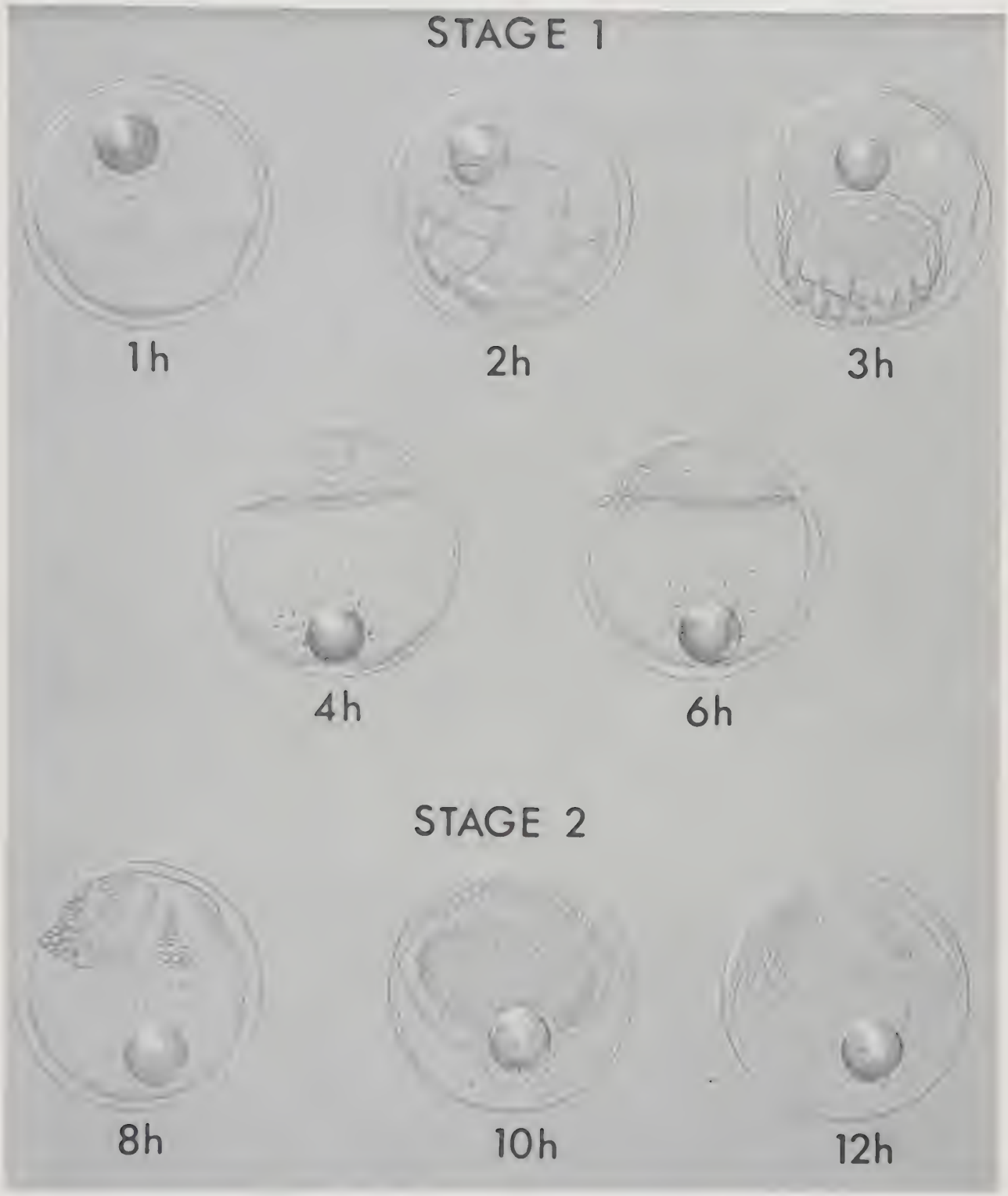


Fig. 10 (above and following pages): Snapper egg development. Individual drawings are variously orientated so that the pertinent features of each stage are best illustrated. Times are for an incubation temperature of 21°C

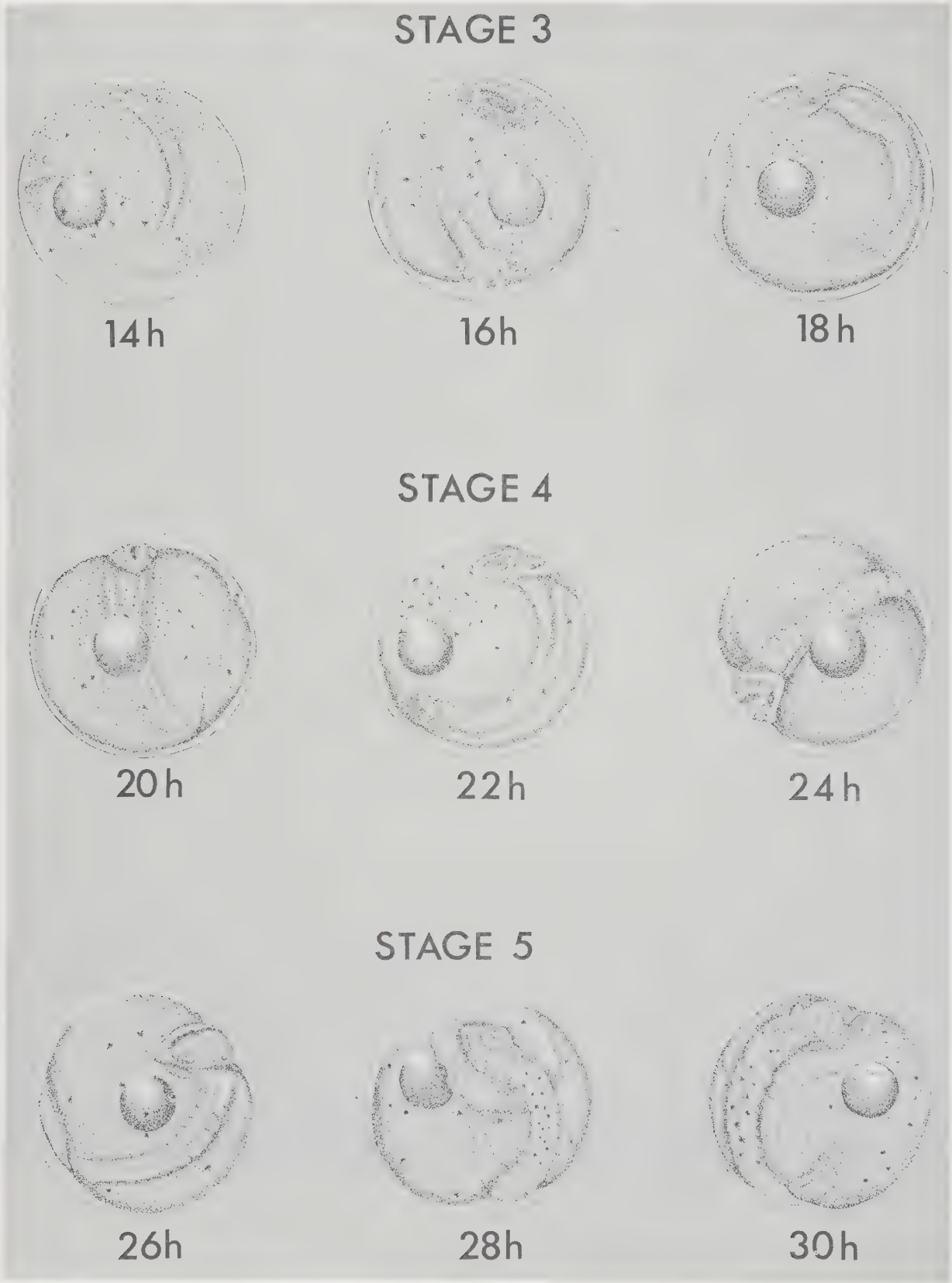


Fig. 10—*continued.*

Fig. 10—*continued.*

CALCULATION OF MORTALITY RATES

The discontinuous spawning pattern made it difficult to calculate a mortality rate from the crude data. Eggs of stage 1 had a good chance of being sampled, as most were spawned during the sampling period, but most eggs passed through stage 2 and much of stage 3 when there was no sampling. The mean length of an egg stage at the sea temperatures in the Hauraki Gulf was slightly less than 8 hours, so that stages 1 and 4 are about 24 hours apart, as are stages 2 and 5 and stages 3 and 6, with the two stages in each pair having almost equal chances of being sampled. My initial approach was to calculate mortality rates for each of these pairs, since for a constant rate these should theoretically give similar results. This worked well for the data from the 1975–76 samples, but was unsatisfactory for 1974–75 because stage 5 contained more eggs than stage 2. It is not uncommon for later stage eggs to be more numerous than earlier stage eggs, if by chance a major spawning occurred the day before sampling. Ahlstrom (1954) found it necessary to remove from his counts of aged sardine eggs one large sample of older eggs. To reduce this effect the method finally used here was to group the data and compare the totals of stage 1–3 eggs (N_0) with stage 4–6 (N_1), so that over the embryonic period the instantaneous mortality rate (Z) = 2 $\log_e$ (N_0/N_1). The factor 2 was used because the interval between the two points was half the embryonic period. This gave, in 1974–75, Z = 1.01 (64% mortality) and in 1975–76, Z = 0.297 (26%).

Although I could not evaluate a standard error for the mortality rates, it is useful to consider a possible source of error caused by the non-random sampling plan. All stations were occupied in the same sequence at about the same time of day on each cruise, which means that the probability of sampling eggs of the same stage differs between stations. Thus, for example, if a station where spawning was heavy were consistently sampled in the early afternoon, it would record much higher numbers of stage 1 eggs than if it had been sampled early in the morning, before appreciable spawning had begun. Taft (1960, page

TABLE 5: Numbers of eggs ($\times 10^{-9}$) by stages

Cruise		Stages 1	2	3	4	5	6
1974–75							
SE1		101	75	80	24	79	22
SE2		355	66	113	41	115	32
SE3		312	28	86	198	44	88
SE4		32	36	114	206	4	51
SE5		101	9	17	48	23	19
SE6		177	8	3	23	13	1
	Totals	1 078	222	413	540	278	213
	%	39.3	8.1	15.1	19.7	10.1	7.8
1975–76							
SE3		48	41	102	33	43	13
SE4		38	58	75	39	44	71
SE5		242	16	39	99	15	56
SE6		27	19	36	88	6	61
SE7		36	25	33	82	39	40
SE8		22	2	6	9	6	2
	Totals	413	161	291	350	153	243
	%	26.6	10.0	18.1	21.7	9.5	15.1

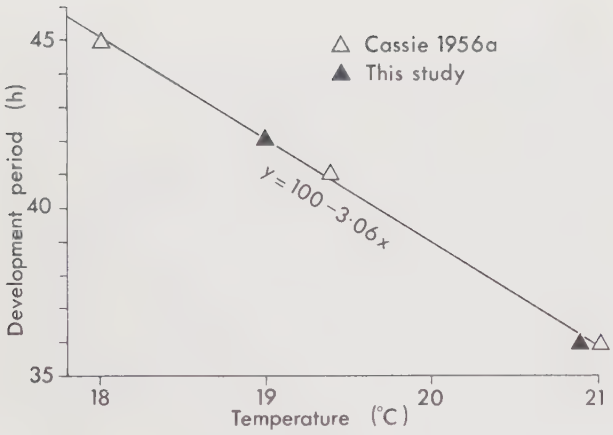


Fig. 11: Effect of temperature on length of development period for the snapper egg.

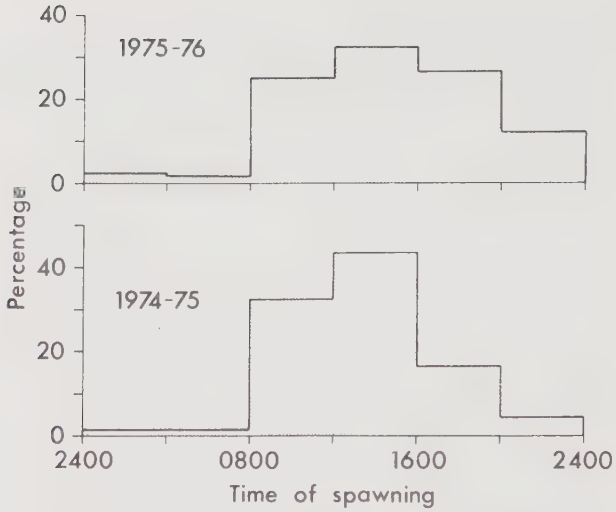


Fig. 12: Daily spawning pattern of the snapper.

263), in a statistical estimation of numbers of sardine eggs, noted that "The mean level observed depends very markedly on the time of arrival of the research vessel at a particular station. For instance, the order of occupancy and position from which a survey vessel starts may strongly influence the number and distribution of eggs collected."

Egg mortality is likely to vary greatly depending on climatic conditions, predator density, and other factors. The observed mortality rates for the two years were therefore considered to reflect a real difference rather than unreliability in their estimation and were used separately in later calculations of egg production. The mean rate (Z = 0.33 per day) is, however, useful for comparison with that found by Smith (1973) for sardine eggs; he recorded a mean daily rate of Z = 0.31 from data extending over the period 1951–59.

ESTIMATES OF ANNUAL EGG PRODUCTION

COMPUTATION METHODS AND RESULTS

These computations make the assumption that the eggs were distributed evenly, and sampled equally, throughout the water column.

First, the daily egg production for each station on each cruise was calculated. The observed number of eggs (n_{ij}) produced per day at the ith station on the jth cruise equals $v_i.d_{ij}/e_{ij}$, where v_i is the volume of water represented by the ith station, d_{ij} is the egg density, and e_{ij} is the embryonic period in days. Not every station was sampled on every cruise (see Table 1) and so estimates of egg density were used for those stations not sampled. These were the arithmetical means of egg densities from adjacent cruises. To calculate the station volumes the station areas were first measured. This was simple for standard areas, which were 5 × 4.33 nautical miles (1974–75) and 4 × 3.46 (1975–76). The method used for non-

standard areas was to mark out the sampling plan on the chart for the area, cut out the areas, weigh them, and evaluate them by comparison with the weight of a standard area. Volumes were then found by multiplying by the mean depth from the chart soundings plus half the mean tidal range.

Station counts were summed to give the observed number of eggs produced per day in the study area on the jth cruise, Σn_{ij}. Integration over time was achieved by weighting the cruise totals by the duration of the cruise plus half the time interval between adjacent cruises on each side. If t_j is time in days represented by the jth cruise, the observed number of eggs produced (C_j) over the period is $t_j \Sigma n_{ij}$, and the observed production for the whole spawning season is ΣC_j. This quantity was then adjusted for egg mortality to give the final estimate of total egg production (P). If m_s is the mortality factor for the spawning season, the total annual production equals $\Sigma C_j/m_s$. The factor m_s was found by calculating what fraction of the total eggs produced was available for sampling over the embryonic period (Fig. 13). This was evaluated by integrating the function $N = N_0\, e^{-Zt}$ from $t = 0$ to $t = 1$, where $t = 1$ = embryonic period; N = fraction available at time t; N_0 = fraction available at time 0 (= 1); and Z = instantaneous mortality rate, that is

$$m_s = \int_0^1 N_0\, e^{-Zt} dt = \frac{N_0\,(1 - e^{-Z})}{Z}$$

Values found for m_s were: 1974–75, 0.63; 1975–76, 0.87.

Details of the observed daily production for each cruise, period intervals, cruise totals, and the computation of annual egg production are shown in Table 6. Two estimates of P are shown for the 1974–75 season: the first, 38×10^{12}, is for the whole area sampled; the second, 37×10^{12}, is for an area equivalent to the reduced area sampled in 1975–76. In 1975–76 the estimate of P, 17×10^{12}, was less than half that of the previous year. However, it is interesting that though the numbers of eggs spawned differed so greatly in the two years, when the observed mortality rates were applied to these estimates, the resulting numbers of eggs surviving to hatch were similar: 12×10^{12} in 1974–75; 13×10^{12} in 1975–76.

RELIABILITY OF RESULTS

Integration over space

A sample count used to estimate the egg total for the surrounding station area is subject to two sources of error: the error in taking the sample (single haul variability) and the error in the assumption that the sample count is representative of the whole station area.

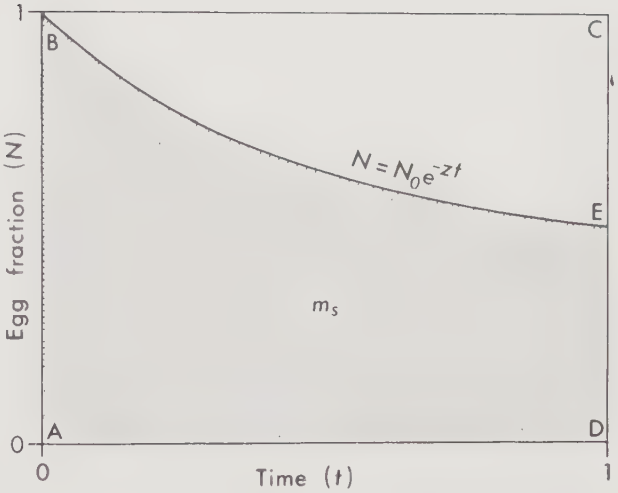


Fig. 13: Schematic representation of the egg mortality factor (m_s): m_s equals area ABED divided by area ABCD, which is the area under the curve $N = N_0 e^{-Zt}$.

Single haul variability was studied by Silliman (1946), who concluded (page 79) that "...the egg

TABLE 6: Calculation of egg production (P) for the 1974–75 and 1975–76 seasons after allowing for the mortality factor (m_S)

Cruise	Daily production ($\times 10^{-9}$)	Period (days)	Period totals (C_j) ($\times 10^{-9}$)
1974–75			
SE0	(30)*	14	(420)
SE1	196	14	2 744
SE2	365	14	5 110
SE3	405	14	5 670
SE4	269	14	3 766
SE5	178	17.5	3 115
SE6	164	17.5	2 870
SE7	36	14	504
			ΣC_j = 24 199
			m_s = 0.63
			$P = C_j/m_s = 38 \times 10^{12}$
	For the area equivalent to that sampled in 1975–76, $P = 37 \times 10^{12}$		
1975–76			
SE1	11	14	154
SE2	41	14	574
SE3	150	14	2 100
SE4	166	14	2 324
SE5	250	14	3 500
SE6	213	14	2 982
SE7	163	14	2 282
SE8	50	14	700
SE9	25	14	350
			ΣC_j = 14 966
			m_s = 0.87
			$P = 17 \times 10^{12}$

*Figures in parentheses are estimates.

number from one haul may not be considered significantly different from the egg number at another unless it is less than one-half, or more than double, that of the other." This error will apply randomly to a series of samples (as in this study) so that the possible total error is likely to be much less than for a single sample. However, it is important to remember that where only a few station counts make up the bulk of a cruise total, as in SE6 (1974–75), where station 30 contributed 76%, this error may be quite large. No estimate of single haul variability was made here, but Sette and Ahlstrom (1948) estimated that it contributed 5%–10% to the error in the seasonal total; de Ciechomski and Capezzani (1973) estimated it at 9%. This type of error could be expected to be of similar magnitude in independent studies.

The variability of egg counts between stations, which is much greater than single haul variability, is a source of potentially large error. Taft (1960), in a statistical study on sardine eggs, fitted the egg counts to a negative binomial distribution, obtained variance estimates, and concluded (page 263) that cruise totals had "...a sampling error such that the true value may be one-half or double the estimated value." Use of this technique implies that each station has an equal chance of containing an egg count within the observed range. This may be true in some study areas, but does not apply to snapper spawning in an enclosed in-shore ground like the Hauraki Gulf, where some stations consistently returned low counts and others consistently high ones.

Mathematical methods of estimating confidence intervals can reflect only the degree of variability of the sample counts and not the accuracy with which they are made. For a fixed number of samples this variability may be equally great in areas widely different in extent. For example, if the egg densities by cruise found in this study are analysed by normal probability methods, they give coefficients of variation in the order of 150%–300%, with individual densities (numbers per 50 m^3) in a single cruise varying from 0 to 6328. It is unlikely that this degree of variability would have been exceeded had the sample stations been spaced along the whole New Zealand coastal area. I concluded, therefore, that the error arising from spatial integration, though potentially large, could not be reliably quantified, and that there was no real value in predicting confidence limits for the cruise totals based on fitting the raw (or transformed) data to a probability distribution. It is likely that several different distributions would have been required to fit all the sets of data, if indeed a fit could have been attained.

Integration over time

The errors arising from temporal integration are also most difficult to estimate with any statistical reliability. To get some idea of their magnitude I have tried an empirical approach. Table 7 shows the estimates of observed egg production calculated by use of egg densities from alternate cruises in each year; two estimates were possible for each year. Comparison of these with estimates using data from all cruises in each year (Table 6) shows that the two estimates for 1974–75 from four cruises were 3% and 5% greater than the estimate from eight cruises; for 1975–76 the estimate from four cruises was 8% less, and from five cruises 1% less, than the estimate from all nine cruises. The error from integrating between consecutive cruises should be less than from alternate cruises, and thus error from temporal integration should be considerably less than the possible error from spatial integration.

TABLE 7: Seasonal totals (ΣC_j) of observed egg production estimated from alternate cruises

Cruise	Daily production ($\times 10^{-9}$)	Period (days)	Period totals (C_j) ($\times 10^{-9}$)	Cruise	Daily production ($\times 10^{-9}$)	Period (days)	Period totals (C_j) ($\times 10^{-9}$)
1974–75							
SE0	30	21	630	SE1	196	35	6 860
SE2	365	28	10 220	SE3	405	28	11 340
SE4	269	29.75	8 003	SE5	178	33.25	5 919
SE6	164	40.25	6 601	SE7	36	22.75	819
		$\Sigma C_j = 25.4 \times 10^{12}$				$\Sigma C_j = 24.9 \times 10^{12}$	
1975–76							
SE1	11	21	231	SE2	41	35	1 435
SE3	150	28	4 200	SE4	166	28	4 648
SE5	250	21	5 250	SE6	213	28	5 964
SE7	163	28	4 564	SE8	50	35	1 750
SE9	25	21	525				
		$\Sigma C_j = 14.8 \times 10^{12}$				$\Sigma C_j = 13.8 \times 10^{12}$	

ESTIMATES OF STOCK ABUNDANCE AND BIOMASS

MEAN FECUNDITY

Estimates of snapper fecundity, the relationship between fecundity and length for the two spawning seasons, and the length at first maturity were made in a previous paper (Crossland 1977b). To combine these with egg production for population estimates it was necessary to find the mean size of a spawning female. To do this the length-frequency distribution of 2858 fish of 23 cm or longer was computed. These data were collected during snapper surveys in 1973–74 by the research vessel *James Cook* in the Hauraki Gulf. Because not all fish between 23 and 29 cm were mature, the numbers were adjusted in this size range. For a long-lived fish like snapper, with a wide range of sizes in the population, the mean weight does not correspond to the weight at mean length. To find the mean weight ($\overline{W}$) the weights per 1-cm length class (W_l) were multiplied by their respective length fractions (f_l) in the population and summed over the range l = 23 to 66 cm, that is $\overline{W} = \Sigma f_l W_l$. Snapper above 66 cm contributed less than 0.01% of the population by numbers. W_l was computed from the relationship:

$$\log_e W = 2.755 \log_e L - 2.981$$

where L is the fork length. This relationship was derived from 209 data points between 22 and 72 cm.

The mean weight of a spawning female (716 g) having been found, the corresponding length at mean weight was obtained (32 cm), and by substitution into the fecundity equations for the two spawning seasons, the mean fecundity (F) was evaluated for each:

1974–75, F = 996 000; 1975–76, F = 456 000.

SEX RATIO

The final factor needed for the population estimates was the proportion of females in the population (K). Colman (1972), during a study on the food of snapper in the Hauraki Gulf, sexed 4980 fish of which 2599 (52.2%) were males and 2381 (47.8%) females. This ratio is used here.

CALCULATIONS OF STOCK ABUNDANCE AND BIOMASS

Population numbers of the mature stock (M) for the two years were calculated by use of the equation $M = P/KF$ and gave:

1974–75, $M = 77.7 \times 10^6$

1975–76, $M = 77.9 \times 10^6$

The 1974–75 figure was adjusted to make it equivalent to the area sampled in 1975–76.

The mean weight of a mature fish, 716 g, was used to compute the stock biomass (B). Estimates were:

1974–75, B = 55 600 t

1975–76, B = 55 700 t

DISCUSSION

There are numerous sources of error in egg surveys, but despite this disadvantage they are becoming increasingly used for stock estimations. Pioneering workers such as Buchanan-Wollaston (1923) and Sette and Ahlstrom (1948) described their methods in detail and made lengthy evaluations of sampling errors, and for this reason their studies were more useful in the planning of this survey than most later ones. Saville (1964), in his review of the theory of egg surveys and the techniques of different workers, considered that the use of egg or larval surveys was the only practical way of estimating the absolute abundance of the adult fish stock, and that sampling problems were reduced if the sampling area was small and the spawning season short.

The size of the sampling area is likely to be the critical factor in most studies. Because there are limits to resources, the extent of the sampling area usually determines the station density which can be worked and thus the magnitude of the station areas over which egg counts are integrated. The study area in the Hauraki Gulf met Saville's size criterion well, and at about 800 square nautical miles it was much smaller than those of other published surveys. Sette and Ahlstrom (1948) covered an area of 19 000 square miles with 40 or 41 stations and considered (page 538) the assumption of linearity in sardine egg concentrations between stations 20 miles apart to be "... materially but not disastrously faulty." However, Smith (1973, page 290) considered that "... the scale of patch involved in the dispersal of sardine eggs appears to be of the order of 10's to 100's of meters patch diameter." De Ciechomski and Capezzani (1973) studied an area of about 45 000 square miles with 78 stations and estimated the errors caused by spatial integration to be 50%.

The consistent pattern of egg distributions found in the 17 cruises during this study indicates that important spawning concentrations are not likely to have been unlocated, and that the distance between stations is appropriate for the size of spawning concentrations. Generally, egg surveys tend towards underestimation, and there is a danger that if stations are widely spaced and there are small dense centres of spawning, these will have a low probability of being sampled.

In integrating over time, the length of the spawning season may not be as critical a factor as the regularity of the spawning curve and the accuracy with which it can be predicted. The snapper's spawning season, though comparatively long at 3–4 months, followed a definite seasonal pattern in both years (Fig. 14), so that a curve of spawning intensity could be drawn with some confidence. On the basis of this, the error in temporal integration does not seem to be as great as that found by Taft (1960), who, in a statistical survey of sardine eggs, showed variability in time to be almost as great as variability in space. However, the area which he studied in detail was only part of a larger spawning area. If the total spawning area is sampled regularly so that local movements and/or changes in spawning intensity of schools or subgroups of the population become part of the whole population's spawning behaviour, these temporal variations will be much less, and they will reflect more closely the overall seasonal pattern. My conclusion from this study is that five sampling cruises would be sufficient to estimate annual snapper egg production in the Hauraki Gulf, provided that their timing allowed for the effect of a warm or cold spring on the commencement of spawning.

The commonly mentioned 95% confidence limits for egg surveys are 50% and 200% of the estimate. Although there has been no attempt to quantify the limits for this study, I believe that they are less. There are considerable data on the population structure and growth rate of snapper in the Hauraki Gulf (Paul 1976, Vooren and Coombs 1977) and on the fishery statistics (Paul 1974) which indicate that the fishery could not be sustained if the stock size were as low as 50% of the estimate here; it is also unlikely to be as high as 200% of the estimate.

The reliability of estimations is also affected by the sampling and counting techniques. These tend to produce a downward bias, which can be kept to a minimum by careful attention to collecting the whole of the sample from the net and rigorous counting methods. The results of a previous study on the fecundity of snapper (Crossland 1977b) showed how greatly this could vary between seasons and the necessity to make separate estimates for each year in which an egg survey is undertaken, otherwise the error in calculating population size will be further undefined and may be considerable.

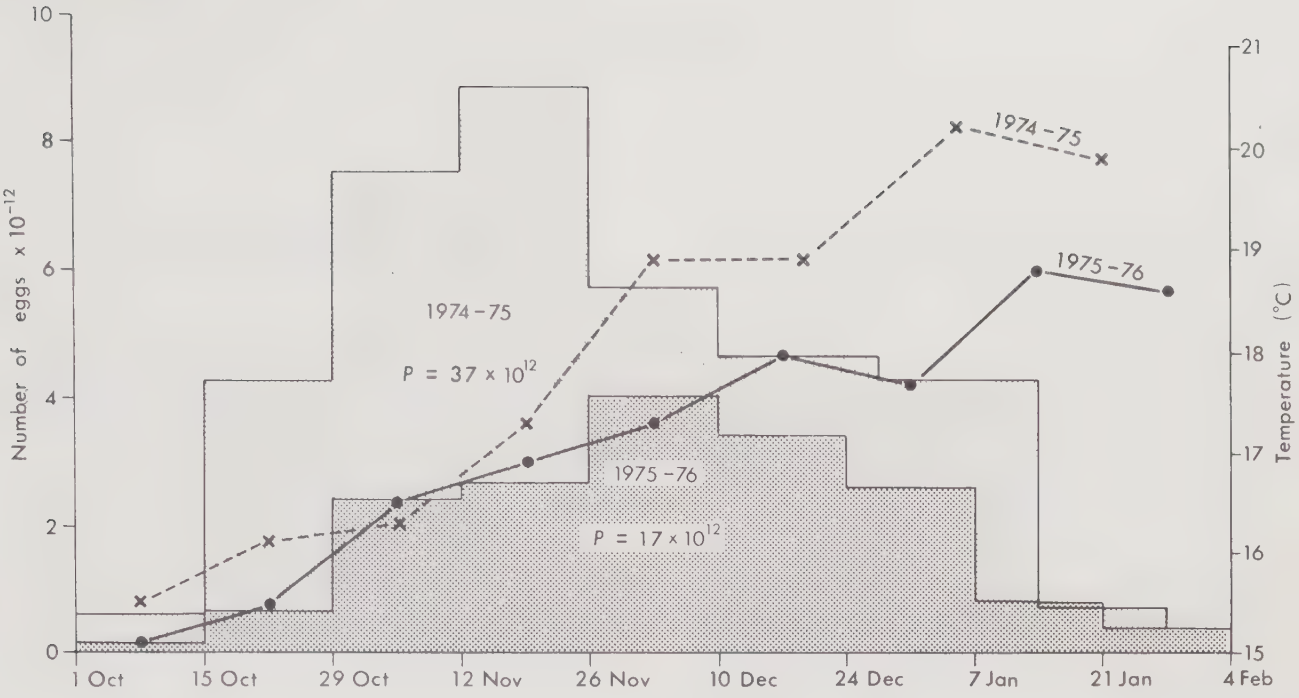


Fig. 14: Snapper egg production and mean sea temperatures by cruises, 1974–75 and 1975–76. *P* is total annual production.

SUMMARY

Estimates of the size of the mature stock of snapper, *Chrysophrys auratus,* in the Hauraki Gulf were made from egg surveys during the 1974–75 and 1975–76 spawning seasons. The study area, which was about 800 square nautical miles, contained 50 sampling stations. These were sampled on seven cruises in 1974–75 and nine in 1975–76, at 2-weekly intervals over the October-January spawning season. Eggs were present at all depths in the water column and were sampled with oblique tows of a cylinder-cone plankton net with a mouth area of 0.25 m^2.

Spawning was concentrated mainly on the western side of the Hauraki Gulf, with the densest patches of eggs occurring from Tiritiri Matangi Island to Flat Rock. Spawning reached a peak in late November-early December. It was later by 2–3 weeks in 1975–76 than the previous year, probably because of lower sea temperatures.

Egg mortality was studied in both years. In 1974–75 the instantaneous rate over the embryonic period (2 days) was 1.01 (64%); in 1975–76 it was 0.297 (26%). The aging of eggs collected at known times showed that snapper had a distinct pattern of daily spawning which began 3–4 hours after dawn, peaked in the early afternoon, and continued until dusk.

Estimates of egg production were made by calculating daily production over the whole area for each cruise, weighting this for the cruise intervals, and summing for the whole spawning season. These totals were adjusted for the observed egg mortalities to give egg production figures of 37 $\times$ 10^{12} in 1974–75 and 17 $\times$ 10^{12} in 1975–76. Estimates of stock numbers and biomass were obtained by combining the egg production with fecundity data for the two seasons, the sex ratio, and the mean fish weight. In 1974–75 the estimated number of mature fish was 77.7 $\times$ 10^6, with a biomass of 55 600 t; in 1975–76, 77.9 $\times$ 10^6 and 55 700 t.

Sampling errors were discussed. The variability and clumped distribution of the egg counts made it inappropriate to apply standard statistical methods in the analysis of error in spatial integration; the prediction of confidence intervals was not attempted. Errors caused by temporal integration were thought to be less than those caused by spatial integration.

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